Coastal Engineering Technical Note

BULKHEADS - THEIR APPLICATIONS AND LIMITATIONS

PURPOSE: To describe the functional applications, limitations, and the general design concepts of bulkheads. This note is intended to provide a brief, general discussion of bulkheads for Corps personnel who do not have a background in the functional design of coastal structures, and to provide useful information for answering inquiries from the general public concerning the construction and use of bulkheads.

FUNCTIONAL APPLICATIONS: The primary purpose of a bulkhead is to retain or prevent sliding of the land, with the secondary purpose being to afford the upland protection from wave action. Bulkheads are normally vertical walls, either piling or gravity-type structures, which are not generally exposed to severe wave action. Bulkheads are used where one or more of the following conditions applies:

1. Wave exposure, and the resulting scour of the fronting beach, occurs infrequently.
2. Loss of the fronting beach is an acceptable trade-off to protect the uplands behind it.
3. The shoreline has a steep bottom profile and is already lacking any beach.
4. The toe of the bulkhead will always be submerged.

Condition 1 occurs when a bulkhead retains backshore property high enough on the beach that it is exposed to waves only when severe storm surges occur. Condition 2 depends on the value of the protected property as compared to the value of the lost beach, while Condition 3 may occur along the base of coastal bluffs. Condition 4 applies to reclamation work where fill is being extended into submerged areas, and to harbor construction where a depth of water adequate for the mooring of boats must

be provided next to a wharf. Bulkheads are frequently used along channels and marina-type developments to separate, and hold the land from the deeper water channels and berths.

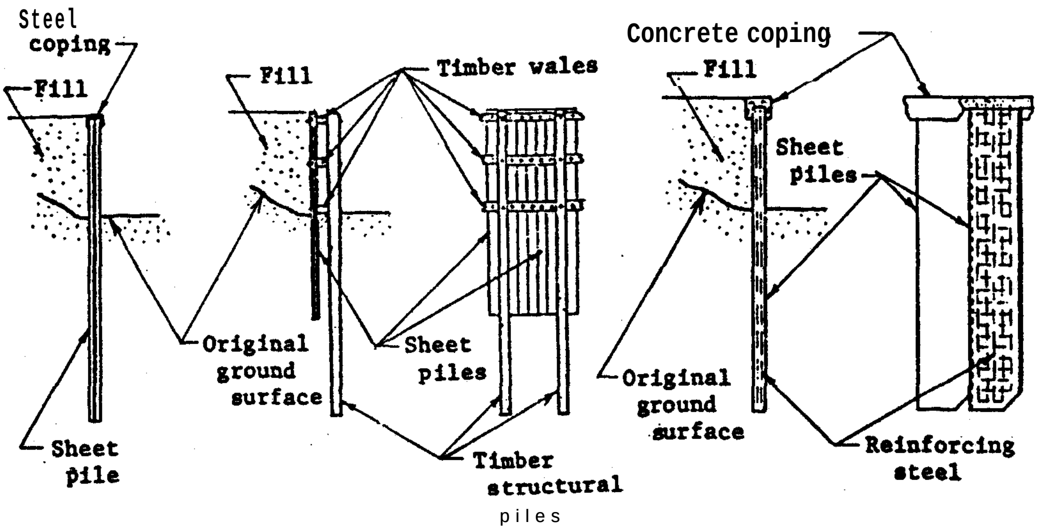
FUNCTIONAL LIMITATIONS: A bulkhead, by itself, may not provide stability to a bank. If a bulkhead is placed at the toe of a bank that has been steepened by erosion to the point of incipient failure, the bank above the bulkhead may slide, burying the structure or carrying it seaward. To insure the structure's success, the bulkhead may have to be placed seaward of the bank's toe and/or the bluff be graded to a flatter, more stable slope. Bulkheads are limited to protecting only the land Immediately behind them, offering no protection to adjacent areas up- or downcoast or to the beach fronting the bulkhead. On an eroding shore, recession of the surrounding shoreline will continue and may be accelerated by wave reflection effects in the vicinity of the bulkhead. If nearby beaches are being supplied with sand by the erosion of the area protected by a new bulkhead, these beaches will be starved and will experience increased erosion. If a beach is to be retained adjacent to a bulkhead, additional structures will be required.

Because bulkheads are normally constructed with a vertical face for constructibility and cost efficiency, wave reflection is maximized, increasing in turn the height of waves at the bulkhead and overtopping potential, and scour in front of the bulkhead. Since such scour can be a serious problem with bulkheads, toe protection may be necessary to insure their stability.

Bulkheads are highly vulnerable to flanking; therefore, it is essential for their ends to be extended landward an adequate distance into the retained area to prevent flanking.

STRUCTURAL ASPECTS: There are three main types of bulkhead structures: cantilever, anchored or braced, and gravity. Each type differs in the way it withstands the lateral earth pressures. Cantilever bulkheads are the simplest and consist of a wall of sheet-piling, which derives its lateral support solely by ground penetration (see Figure 1). Anchored or braced bulkheads are similar to cantilever structures, but gain additional support against seaward deflection from anchors set sufficiently far back in the bank, as shown in Figures 2 and 3; or from battered structural piling on the seaward side of the bulkheads as shown in Figure 3. Gravity bulkheads include rock-filled cribs and sheet-pile cells, as shown in Figures 4 and 5,

respectively. They depend on their weight and the width of their bases to maintain stability against overturning and to develop sufficient friction with the underlying soil to prevent sliding seaward.



(a) Steel (b) Timber (c) Reinforced concrete

Figure 1. Cantilever Sheet-Pile Bulkheads

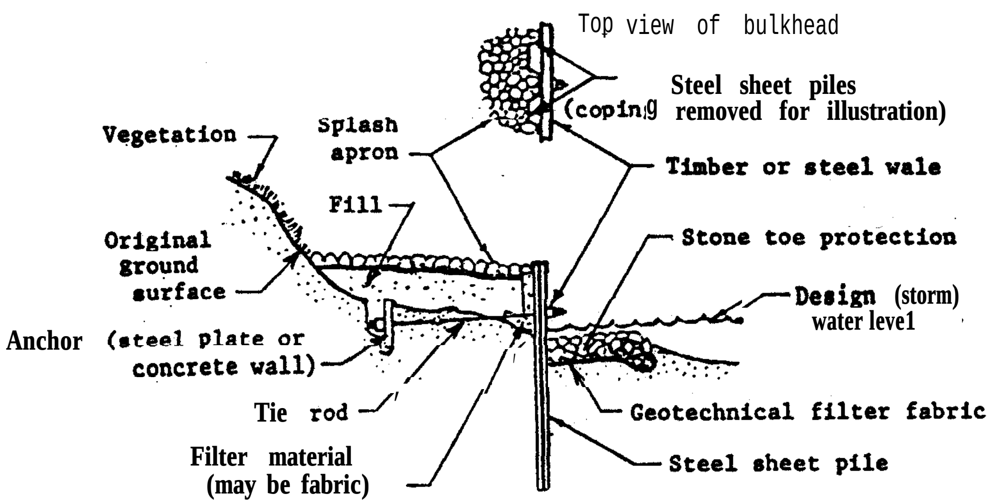


Figure. 2. Anchored Steel Sheet-Pile Bulkhead

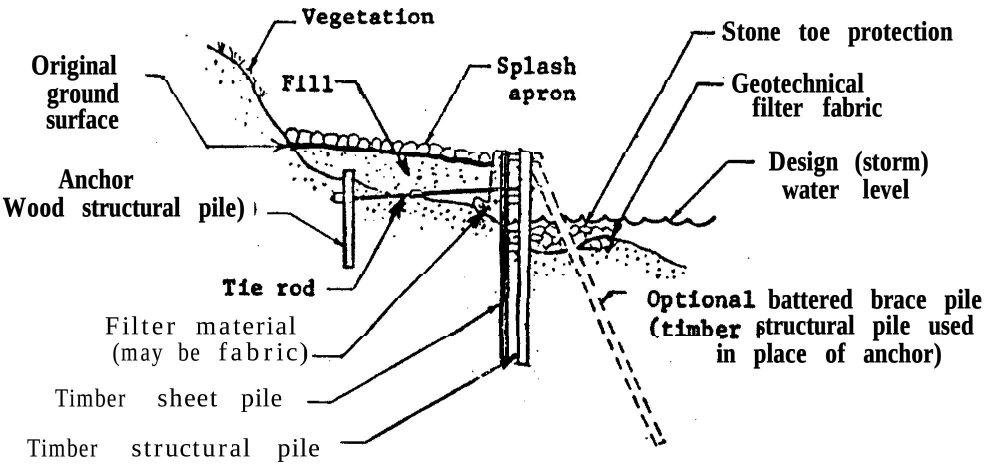


Figure 3. Anchored or Braced Wood Sheet-Pile Bulkhead

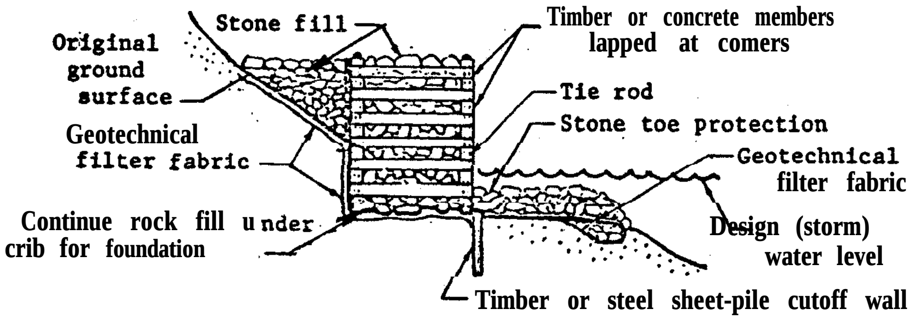
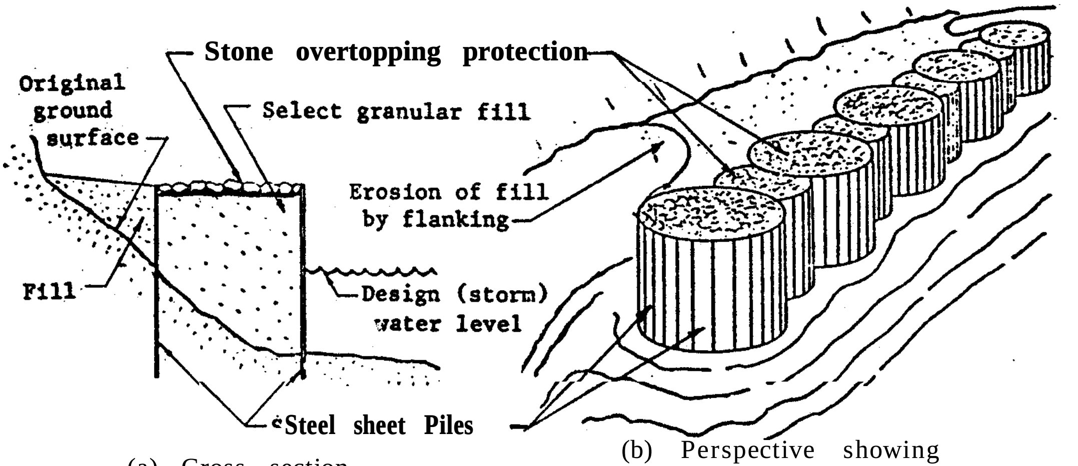


Figure 4. Rock-Filled Crib Bulkhead



(a) Cross section

(b) Perspective showing effects of flanking

Figure 5. Cellular Steel Sheet-Pile Bulkhead

Cantilever bulkheads are the most susceptible to failure by toe scour because of their sole dependence on ground penetration for lateral support. Anchored and braced bulkheads, because they are better supported and better able to resist lateral earth pressures, are the type most commonly used in the coastal zone. Anchors may be buried horizontal beams or plates, as shown in Figure 2, or vertical piles, as shown in Figure 3. Cells and rock-filled cribs may be used where foundation conditions will not economically permit adequate penetration to develop support for anchored or braced sheet-pile bulkheads. Both require banks that are stable with the gravity structure in place, and foundation soil that is safe against unacceptable settlement. Cells and cribs must be designed to prevent racking. (the flattening of the structure under lateral forces). Cribs, with limited resistance to rotation and sliding, usually are restricted to use where the level of fill behind the bulkhead is about equal to the height of the bulkhead.

All three types of bulkheads both reflect wave energy and increase the water velocities, which may increase the scour at the toe. Scour wi11 reduce the piling's depth in the ground and effective soil support, and undermine the base of gravity structures; therefore, toe protection should be an integral part of bulkheads. Typical toe protection, shown in Figures 2, 3, and 4, consists of quarrystone large enough to resist movement by wave forces, with an underlying layer of granular material and/or geotechnical filter fabric to prevent soil from being washed through voids in the scour apron. Sheet-pile structures must be designed to have adequate penetration both for the expected lateral loads and any expected scour. To prevent undermining, gravity structures may require a sheet-pile cutoff wall as well as an apron, as shown in Figure 4.

Tides, storm surges, and overtopping can rapidly raise the ground water level in the retained soil. This head drop across the bulkhead wi11 increase the hydrostatic force on the bulkhead, and induce seepage under the bulkhead which may contribute to scour of the soil at the Toe. Additional drainage through the face of the bulkhead is provided with naturally permeable rock-filled cribs, but, with pile structures, drainage holes should be added. The pore water pressure due to excess accumulation of water can be controlled by paving the ground surface behind the bulkhead,

designing the heights of the bulkhead to eliminate overtopping, and installing proper drainage controls at the top of and within the retained bank. Flow under the toe can be stopped or reduced by the cutoff wall mentioned above, or by increasing the penetration of sheet-piles.

The retained soil provides the bulkhead an additional resistance to wave forces. If the soil is eroded, the bulkhead loses support and may fail under wave action. Joints and holes in the bulkhead should be backed by filter material to allow drainage while still preventing loss of the retained soil. Any lifting holes in sheet-piles below the retained soil line should be covered with plates or backed by filter material. If the bulkhead will be overtopped and the ground surface behind the bulkhead is not paved, a splash apron, usually armor stone with a graded quarrystone filter, as shown in Figures 2, 3, and 4, must be built on top of the retained soil to prevent its removal by waves. Paved surfaces may become separated from the bulkhead leaving an open joint through which overtopping waves may erode the underlying fill material. A filter of gravel or geotechnical fabric against the bulkhead and under the asphalt can prevent this material loss. Each end of a bulkhead must be tied into adjacent shore protection structures or extended back into the existing bank a sufficient distance to prevent the erosion of the laterally adjacent shore from advancing into the retained soil, a process called flanking. Flanking of a cellular bulkhead is illustrated in Figure 5 (b).

<u>MATERIALS</u>: Timber, steel, aluminum, and concrete sheet-piles are the most common bulkhead materials. Steel, aluminum, and concrete sheet-piles do not require support by structural piless although concrete bulkheads have been built using concrete slabs supported by structural kingpiles. Timber sheet-piles commonly have a supporting framework of wales and structural piles, as shown in Figure 3. Pattered pile props are usually used only for timber bulkheads, although tie-back anchors are generally used with sheet-pile structures of all materials. Steel-piling are used where the soil is dense or contains rocks or logs, and is preferred for high bulkheads. Cells are built of steel sheet-piling. Cribs are usually built of timber, but may also be built of concrete or steel members. When bolts are used for fasteners, most commonly for timber structures, they must be tightened securely to prevent loss of structural rigidity, the resulting breakage of members, and the eventual failure of a structure through loss of retained fill. Steel should

have cathodic protection or appropriate coatings to control corrosion in saltwater. Timbers should be pressure-treated with preservatives to prevent rot in freshwater and fouling and other infestations in saltwater, especially marine borers in warm water.

DESIGN CONSIDERATIONS FOR BULKHEADS:

1. If the bulkhead fronts a beach which cannot be sacrificed, a beach fill and additional protective structures may be required. If access to the beach is desired, stairs over the bulkhead can be added.

2. Earth pressures on the landward side of the bulkhead are the main design considerations, but wave forces on the seaward side should also be considered. Adequate resistance to the wave forces will be provided by the landside fill if it is maintained in place. Resistance to earth pressures can be provided by proper design of the bulkhead. Crib and cellular-type bulkheads should have adequate weight and base width. Sheet-pile structures should have sufficient pile penetration and tie-back anchor capacity. In order to decrease bank steepness and corresponding earth pressures, the bank could be graded or the structure moved seaward. To determine earth pressures on bulkheads, refer to EM 1110-2-2502,"Engineering and Design of Retaining Walls" (currently being revised by Tulsa District, Corps of Engineers).

3. A bulkhead should resist the effects of wave-induced scour. Such scour may result in decreased pile penetration or Undermining of cribs. Sheet-piles can be driven deeper than required in the absence of scour; sheet-pile cutoff walls can be added at the toes of cribs, and armored toe scour aprons can be used with any type of structure.

4. Although rainwater will run off onto the backfill, overtopping increased by wave reflection may also add water to the backfill behind the bulkhead. This would increase the weight of the backfill and could increase the backfill scour. Measures to prevent or control overtopping are discussed in CETN-III-8 (Seawalls).

5. Steps need to be taken to eliminate the removal of backfill by ground water flowing through a bulkhead, and the loss of toe soil by water flowing under the structure. Drains in the bank or backfill and means to control overtopping will reduce the volume of ground water at the back of

the bulkhead; while drain holes in the bulkhead, backed by filter material, will allow drainage through the structure itself. Increasing the penetration of sheet-piling, adding a cutoff wall, and using an apron of filter material can reduce or eliminate the scouring effects of flow under the bulkhead.

7. The bulkhead must be safe against failure due to flanking. The ends must be tied to adjacent structures or turned back into the shore or upland.

MATERIAL SELECTION FOR BULKHEADS:

1. Sheet-pile bulkheads require pile drivers for construction and may require pile removal equipment for repair. Access to the construction site must be available for such equipment. Installation of steel and concrete sheet-piles involves skilled labor, high material and fabrication costs, and heavier construction equipment than used for timber sheet-piles.

2. Pretreatment to retard deterioration is always required for timber and may be required for saltwater uses of steel and aluminum. In additlon, maintenance is necessary to control the rotting and splintering of wood, the corrosion of metals, and the spalling of concrete. Timber structures often can be repaired by bolting new members over broken ones or in place of damaged sections, but damaged components of steel, aluminum, and concrete structures must be entirely replaced.

REFERENCES:

U.S. ARMY, CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, *Shore Protection Manual,* 3d ed., Vols. I, II, and III, Stock No. 008-022-00113-1, U.S. Government Printing Office, Washington, D.C., 1977, 1,262 pp.

U.S. ARMY, CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, "Seawalls - Their Applications and Limitations," CETN-111-8, Fort Belvoir, VA., 1981.

U.S. ARMY, CORPS OF ENGINEERS, "Retaining Walls," *Engineer Manual, Engineering* and *Design,* EM 1110-2-2502, Washington, D.C. (revision in preparation, 1981).